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ABSTRACT

A model of teacher education (and the system of education; more broadly) that is largely derived from research in ecology is described. Potential problems associated with imposing mechanistic approaches on the ecological system are postulated. Finally, some pedagogical implications are presented. (Contains 30 references.) (Author)

The Ecosystem of Teacher Preparation: Understanding the Complex Educational System

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Abstract:
A model of teacher education (and the system of education more broadly) that is largely derived from research in ecology is described. Potential problems associated with imposing mechanistic approaches on the ecological system are postulated. Finally, some pedagogical implications are presented.

> "You don't see something until you have the right metaphor for it."
> (Bowers, 1990, p. 128)

The objective of this paper is to further develop understandings of the educational system and more specifically, the system of teacher education, as a complex adaptive system. Using ecosystems metaphorically to illustrate relationships within the system allows us to see the system as more akin to industrial agriculture than to other types of industrial models often cited (i.e., the assembly line).

There are a number of metaphorical ways to think about the number of innovators needed to adopt an innovation for it to be durable. One is critical mass; from nuclear physics, the minimum amount of fissionable material to maintain a reaction. Another is the species-area relationship from ecology, the minimum amount of territory needed for a species to avoid extinction. A third example is the tipping point, from epidemiology[1] which is similar to the ideas of flips and flops described by ecologists Reiger & Kay (1996; 2002). In both tipping points and flips and flops, a number of conditions need to come together in such a way that system changes rapidly to a different relatively stable state.

The metaphorical model looks at the system of schooling as an ecosystem with many similarities to industrial agriculture. Both systems are...

- Simultaneously remarkably successful and deeply troubled;
- Highly dependent on initial conditions;
- Often characterized by "first cover," the concept that the first species to cover an open niche will be successful regardless of measures of efficiency;
- Non-linear;
- Confounded by delays in feedback; and
- Human constructs often overwhelmed by factors from outside the system;
- Emergent from multiple human and non-human actors.

This list is far from exhaustive.

This paper directly ties to the conference theme, "Accountability for Educational Quality: Shared Responsibility." Inherent in a systems approach is the understanding of distributed causality. Most problems of the educational system are not attributable to specific individuals or groups of individuals, but rather to the properties of the system that have emerged as a result of gradual systemic evolution (and systemic stasis).

Ultimately, the goal of this line of work is to better understand how to operate more effectively within a complex educational system where one should expect models to be

[1] See Malcolm Gladwell's *The Tipping Point* for an accessible description connected to multiple examples of social change (Gladwell, 2000).

only weakly predictive and to use these perspectives to guide how we might better meet our responsibilities working in the system. And hopefully to do so without being too depressing.

Genesis of an ecosystemic model

This work grew out of a dissertation study that was an outgrowth of the Salish Project (Salish, 1997). In my dissertation study, I investigated the conflict between the way future science teachers are taught to teach science and the way in which they are taught science. I initially viewed the system as two distinct monolithic cultures *a la* C. P. Snow (Snow, 1959). The culture of college science was a lecture-based world and the culture of teacher education was anything but from the student perspective (Duggan-Haas, 1998). The simplification was useful, but too vast. I moved onto a framework of a dysfunctional relationship between science and education *a la* John Grey's *Men Are From Mars, Women are from Venus* (Gray, 1992). This led to viewing the system of science teacher education as a dysfunctional set of relationships (the title of my dissertation speaks directly to this: *Scientists are from Mars, Educators are from Venus: Relationships in the Ecosystem of Science Teacher Preparation).* This was also a vast but useful simplification. The dissertation maps my conceptual change as I studied the system; building one model and then finding it wanting and starting over again informed by what was dissatisfactory from first the and then the second. The third model is introduced in the dissertation, the ecosystem of teacher preparation (Duggan-Haas, 2000). This paper expands on the work done in the dissertation related to the third model. This model, I believe has utility beyond that of the first two.

Educators have examined the system of education using a many metaphorical lenses. Among the most common is an industrial or mechanistic model where students are moved from class to class at the sound of a bell with content added at each stop like widgets moved through an assembly line. Teachers may be given tune ups in the form of a professional development workshops. This linear model is widely recognized as ineffective. Inherent in such a model are the ideas of purposeful *design* and *linearity*. I will argue that the system was not *designed* but rather it *emerged* from a collection of disparate pieces and that the system is not linear but rather rife with cycles.

The framework I employ is derived largely from literature in ecology and complexity, though others have written about chaos, complexity and systems thinking as frameworks for understanding the educational system. Wideen, Mayer-Smith and Moon (1998) suggested the use of an ecological framework in their meta-analysis of learning to teach research. Posner, et al, wrote of conceptual ecologies in describing conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). Hoban uses systems as the framework to describe professional development and its role in the larger system (and failure to understand the nature of the complex system as key to understanding why so many reforms fail) (Hoban, 2002). Hoban indicates that an ecosystemic model of schooling is not new – citing separate works of Seymour Sarason and John Goodlad from the 1970s using ecology to describe the system of schooling. Home economics became human ecology many years ago.

Hoban offers a thorough overview of the mechanistic view of education. He also distinguishes complexity from chaos and opts not to use an ecological lens. The system of schooling, like an ecosystem, is a complex system. Using ecosystems as a lens is useful for understanding the system of education for it allows us to look at complex systems that have been both managed and studied by humans, some of who knew they were working with complex adaptive systems.

While a great many have written and/or taught about the problems of mechanistic approaches, such approaches remain dominant.

> This is evident in how the curricula of teacher preparation courses are often organized for preservice students. In many teacher education programmes, courses focus independently on pedagogy, sociology, learning, assessment, classroom management, technology, evaluation, or discipline knowledge. These courses are often taught to students in isolation to each other because they can study a discrete topic in depth as it easier to for instructors to organize and assess. (Hoban, 2002 p.10)

In *The Logic of Failure,* Dietrich Dörner describes how people operating in perfectly rational ways contribute to the failure of approaches to problems. A common logic of failure is for people to do what they know how to do rather than what needs to be done (Dörner, 1996). I argue that the practice of disaggregating the skills necessary for teaching into separate classes is one example of doing what one knows how to do rather than doing what needs to be done.

"This reductionist approach to educational change assumes that complicated phenomena can be understood by analyzing and identifying all parts or components that make up the phenomena" (Hoban, p. 18). It neglects how the pieces fit together and interact with one another. In what ways do the seemingly disparate pieces of the system interact? What has emerged from the interaction of disparate parts of the system? What can understanding the educational system as a complex adaptive system help individuals within the system to do better?

Modes of inquiry

The dissertation study uses observational data in college science and education classes, interviews with biology teacher candidates and a case study of a collaborative organization of scientists and educators. The study was done at a large mid-western university with a highly regarded teacher education program (referred to here as Midwestern University).

The unit of analysis in such a systems perspective is the "individual in related action" (Hoban, 2002, p. 59 – 65). The heart of the work is not to understand individuals, or even individual monolithic cultures within a system, but the nature of how individual relate to each other both of their own volition and as a result of how their niche within the system pushes them to act and interact.

This paper will not attempt to portray the data collection or analysis in any depth, but rather will focus on the conceptual model development. What this paper does might be described as more analytical and comparative than empirical. For description of data collection and analysis, refer to the dissertation.

Evidence

Two Programs, Two Cultures

Table 1 provides a summary of an interview that was completed both for the dissertation and as part of the Salish Project. The responses typify the nature of much of the data – that college science teaching is vastly different from college teacher education classes. Further, students are largely left to their own devices to integrate the learning from the two contexts.

The analysis of the interview data that is summarized in Table 1, coupled with personal experience working in and having graduated from a teacher education program where students complete an academic major in their certification area and take coursework in teacher education led me initially to see the program as made up of two monolithic cultures as the table illustrates. As noted above, this is a vast simplification of the system. Within the system, there are important interactions among faculty in the sciences and education and among teacher candidates and practicing teachers who host students in their school based fieldwork. The model is a fair place to start, but closer inspection quickly indicates that it doesn't allow you to predict much about what teachers will actually do when they enter the classroom. And after all, isn't prediction a key goal of educational research?

Scientists are from Mars, Educators are from Venus

After beginning with Snow's model, I moved on to models based on John Gray's *Men are from Mars, Women are from Venus*. The characteristics of a dysfunctional marriage are mirrored in the characteristics of science teacher preparation programs. There are two primary components to most such programs – content training housed in colleges and departments of science and pedagogical training housed in colleges and departments of education. The norm is poor communication between these departments, particularly in larger institutions. A central obstacle to this communication is blame.

Characteristic	Science	Teacher Education
Course Instruction	Lecture, "...mostly lecture. Not much labs, not great labs when we had them."	Group work/discussion, "I would say a little bit of everything besides lecture."
Use of lecture	Frequent	Rare
Use of cooperative learning	Rare	Frequent
Class-size	Large	Small
Program purpose/goals	Goals are well-defined and understood: content dissemination; to learn facts	Goals are poorly defined or understood. Many different goals are identified.
Textbook use	Common	Uncommon
Instructional Resources	Textbook	Readings — collections of articles also occasional videos
Methods of assessment	Objective tests, mostly multiple-choice	Written work before the student teaching internship, written work along with teaching performance during the internship.
Teacher-Student relationships	"By far, the commonest words used to describe encounters with S.M.E. faculty are 'unapproachable,' 'cold,' unavailable,' 'aloof,' indifferent,' and 'intimidating.'" (Seymour & Hewitt, p. 141)	Personal; "Excellent," was a term used by half the participants in the national sample to describe the faculty-student relationship in the Salish study.
Program components valued by new teachers	Research or research like experiences – In the original Salish study, two new teachers graduated from Midwestern U reported such experiences; one as a volunteer, the other at a different institution. In most cases, these experiences were outside the formal program.	The full-year student teaching internship; the sequence of courses in TE related to their subject matter. In all cases, these experiences were part of the formal program.
	Partial Summary	
Classroom culture's relation to professional work	Undergraduate science courses do not generally reflect the work of scientists. Unfortunately, they may reflect the work of science teachers.	Undergraduate teacher education courses reflect what teachers should do (in the opinion of teacher education faculty) in their own classrooms.

Table 1: Two Programs, Two Cultures

It is little surprise that students see little relationship between their science and teacher education course work. It seems that every instructional characteristic of one program is reversed in the other. Unless otherwise noted, quotations are taken from New Teacher Interviews of Midwestern University graduates.

(Adapted from Duggan-Haas, 1998)

Educators tend to see science courses as abysmally taught and rightly so, see Seymour and Hewitt (1997) for some of the reasons behind this placing of blame. Scientists often see education courses and education research as "touchy-feely crap," as Jon Peters, one of the introductory biology professors in the dissertation study said. They too have justification for their criticism. Wideen et. al. (1998) draw attention to the fact that teacher preparation has consistently failed to prepare teachers to meet the demands of the first year of teaching. Hargreaves & Jacka (1995) cite Lacey's (1977) conclusion that teacher education provides, "a stressful but ineffective interlude in the shift from being a moderately successful and generally conformist student, to being an institutionally compliant and pedagogically conservative teacher" (p. 42) as cited on page 159 of Wideen et al. When viewed collectively, blaming can be shown to be cyclic. See Figure 1. Evidence for this from the study is primarily anecdotal – university faculty in the collaborative group of scientists and science educators seemingly talking past each other and sometimes placing blame for educational problems on various educational reforms and on each other. Likewise I can cite countless personal anecdotes of teachers I've worked with in various contexts grousing about their teacher preparation and the preparation of their colleagues related to both content and pedagogy.

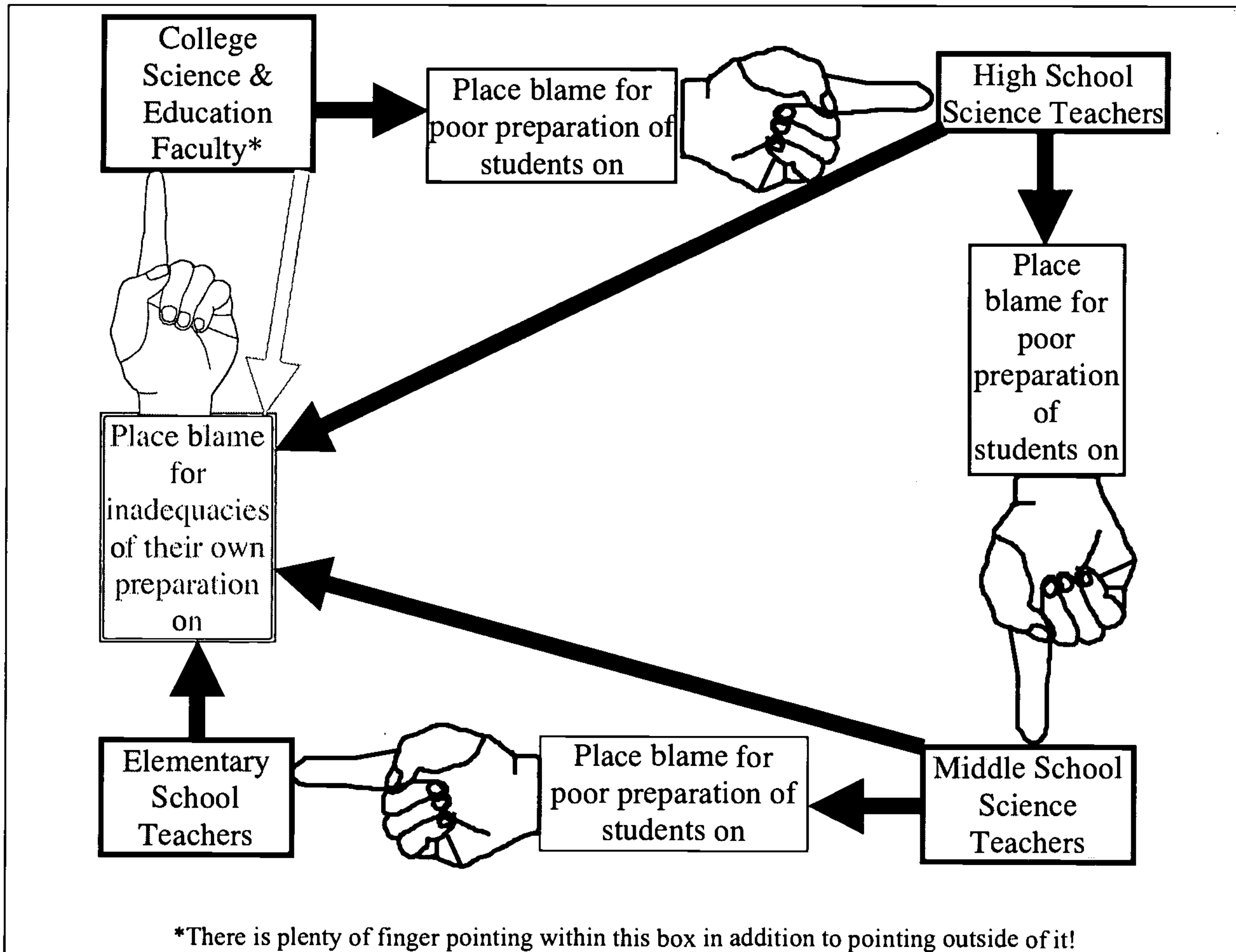

Figure 1: Cycle of Blame (Duggan-Haas, Smith, & Miller, 1999)8}

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While this second model seemed a closer depiction of the realities of the system, it left me wondering what did I know how to do better as a result of seeing the system in this way? Perhaps I could see a need for the intercession of counselors in the relationships within the system or some metaphorical equivalent (and I do believe this is important), but what could I predict based on the model?

The Ecosystem of Science Teacher Preparation

> "Recently the ecologist C.S. Holling has discussed the conflict between "two streams of science" and the confusion it creates for politicians and the public (Holling 1995:12-16, see also Holling 1993:553-4). One stream is experimental, reductionist, and narrowly disciplinary. It is familiar to us as the scientific ideal. The less familiar stream is interdisciplinary, integrative, historical, analytical, comparative, and experimental at appropriate scales. Examples given of the first form are molecular biology and genetic engineering. The second form is found in evolutionary biology and systems approaches in populations, ecosystems, landscapes, and global dynamics. One stream is a science of parts, the other a science of the integration of parts." (Abel, 1998, Pg. 6)

As I worked through the interview and observational data from the dissertation study, I was also reading more about chaos, complexity and ecology. This stretches beyond the completion of the dissertation. Perhaps, my quest for predictably within the system of teacher education was simply foolhardy.

In an ecosystem, an intervention (or attempt to manage the system) or disturbance can yield one of five qualitatively different kinds of outcomes:

- The system can continue to operate as before, even though its operations may be initially and temporarily unsettled.
- The system can operate at a different level using the same structures it originally had (for example, a reduction or increase in species numbers).
- Some new structures can emerge in the system that replace or augment existing structures (for example, new species or paths in the food web).
- A new ecosystem, made up of quite different structures, can emerge.
- The final, and very rare possibility, is that the ecosystem can collapse completely and no regeneration occurs.

(Kay & Schneider, 1994)

It seems that five (and only five) analogous types of change are possible within the complex educational system. It is very important to understand that modeling in complex systems can only be weakly predictive at which type of outcome is likely. Indeed, Kay & Schneider argue: "We will have to learn that we don't manage ecosystems, we manage our interaction with them. Furthermore, the search for simple rules of ecosystem behaviour is futile." The same holds true for management in the educational system.

So, What's the Point? Illustrative Parallels Between Systems

We *can* manage our interactions with the system and make those individual interactions perhaps more likely to yield the kind of change we wish to see. If ecological understandings of complex systems have analogic aspects in the complex educational system, perhaps this can inform the work of professionals within the system; inform how they might more effectively manage their own interactions with the system.

In order to understand parallels between systems, it is important to have a basic understanding of what I mean when I say "system." I refer to systems in the way of complex adaptive systems. Figure 2 is composed of excerpts from Alan AkKisson's *Believing Cassandra,* (1999). Kay (2000) provides a concise description of certain characteristics of complex systems and describes system aspects not described by AtKisson. This is reproduced in Figure 3 below. Table 2 then provides further summary information of complex systems and system dynamics.

Following the brief overview of what makes a system a complex adaptive system, I sketch out a series of parallels between ecology and education, with parallels that, at least for me, help to describe the educational system in new and illuminating ways.

A *system* is a collection of separate elements that are connected together to form a coherent whole. Your body is a system, and it's comprised many smaller systems, all working together: the circulatory system, the digestive system, and so on. The connections between the elements of a system come in two forms: stuff and information. For example you eat food (stuff), and when your belly gets full it sends a signal (information) to your brain telling you to stop eating.

The science of system dynamics uses a lingo, and it is easy to learn. In the example above, the food moving through your gullet would be called a *flow*. Your belly, filling up from the flow of food, would be called a *stock*. And the signal sent to your brain, indicating whether the stock of food in your belly has reached that comforting level known as "full" is called *feedback*.

The feedback from your belly has an impact on your eating behavior, which in turn causes more feedback from the belly. All that circling around of stuff and information, which controls (or should control) how much you eat is called a *feedback loop*. This feedback loop, like most others, operates in two directions: it tells you to stop eating when you are full, and it starts your search for food again when your belly is not full. Feedback loops essentially give one or two messages to the system" "do more" or "do less."

... A critical point to remember: *Delays in feedback slow down response*. You can't react to changes you don't know about. And when you *do* know about changes, you may not have enough time to respond...

Here are two more important systems concepts: *sources* and *sinks*. Sources are where stuff comes from; sinks are where stuff ends up. Farmlands and oceans are the *source* of food you eat. In certain more enlightened societies, farmland is also the *sink* where the compostable residue ends up; for most of us, though, the sink is some local body of water connected with a sewage treatment plant. ... Sometimes even the human body acts as a sink, as when lead builds up in the tissues. The impact of that lead is not felt directly for years, and this is another delay in feedback. By the time you notice the symptoms of lead poisoning, it's too late: you're poisoned, and there is no way to get the poison out fast enough to prevent further damage.

... Obviously, the issue of how quickly we get feedback about what's happening in the sources and sinks is extremely important to understanding and managing systems.

Figure 2: AtKisson's description of system dynamics. (AtKisson, 1999) pp. 69 –72.

Figure 3: Properties of *complex systems* to bear in mind when thinking about ecosystems (primarily from Kay (2000)).

- **NON-LINEAR:** Behave as a whole, *a system*. Cannot be understood by simply decomposing into pieces which are added or multiplied together.
- **HIERARCHICAL:** Are *holarchicically nested.* The system is nested within a system and is made up of systems. The "control" exercised by a holon of a specific level always involves a balance of internal or self-control and external, shared, reciprocating controls involving other holons in a mutual causal way that transcend the old selfish-altruistic polarizing designations. Such nestings cannot be understood by focusing on one hierarchical level (holon) alone. Understanding comes from multiple perspectives of different *types* and *scale.*
- **INTERNAL CAUSALITY**: non-Newtonian, not a mechanism, but rather is *self-organizing.* Characterized by: goals, positive and negative feedback, autocatalysis, emergent properties and surprise.
- **WINDOW OF VITALITY**: Must have enough complexity but not too much. There is a range within which self-organization can occur. Complex systems strive for *optimum,* not minimum or maximum.
- **DYNAMICALLY STABLE?**: There may not exist equilibrium points for the system.
- **MULTIPLE STEADY STATES**: There is **not** necessarily a unique preferred system state in a given situation. *Multiple attractors* can be possible in a given situation and the current system state may be as much a function of historical accidents as anything else.
- **CATASTROPHIC BEHAVIOUR**: The norm
  Bifurcations: moments of unpredictable behaviour
  Flips: sudden discontinuities, rapid change
  Holling four box cycle: shifting steady state mosaic
- **CHAOTIC BEHAVIOUR**: our ability to forecast and predict is always limited, for example to between five and ten days for weather forecasts, regardless of how sophisticated our computers are and how much information we have.

(Kay, 2000)

- **FIRST COVER:** also known as "lock-in" is an ecosystems concept. It refers to the fact that in succession it is often the first plant species to enter or "cover" an open niche that will be successful at a point in time, regardless of some absolute measure of efficiency. This emphasizes the stochastic nature of ecological and evolutionary thinking in the creation of historical scenarios of change in complex systems.

(Abel, 1998)

- **EMERGENT EVOLUTION:** evolution that according to some theories that involves the appearance of new characters and qualities at complex levels of organization (as the cell or organism) which cannot be predicted solely from the study of less complex levels (as the atom or molecule).

(Merriam-Webster's Collegiate Dictionary, Electronic Edition, 1994)

The descriptions in Figures 2 and 3 primarily target ecological systems but maps on to the system of science teacher preparation well. It begins with the important release of blame. The problems of science teacher education are no one's fault. The problems are grounded in a system that has evolved over centuries. No one designed this. Mostly we fill niches in an existing system and we fill those niches in the way the system evolved to have them filled.

Like farmland is both a source and a sink for agriculturally produced materials, schools are both a source and a sink for science teacher candidates. Understanding this cycle benefits both the scientist and teacher educator. It is, in a sense, turning the cycle of blame to advantage.

John H. Holland summarizes the common characteristics of all CASs in his essay, "Can There Be a Unified Theory of Complex Adaptive Systems?" Table 2a uses Holland's descriptors of CAS characteristics and compares complex adaptive systems to science teacher preparation. The numbered text (1 - 7) in the left column is Holland's (pp. 46 - 47). Table 2b includes other descriptors of CASs and examples.

In Complex Adaptive Systems…	Example from Science Teacher Preparation…
(1) All CAS consist of large numbers of components, *agents*, that incessantly interact with each other.	This includes students, faculty, family, community and the media among other agents.
(2) It is the concerted behavior of these agents, the *aggregate behavior,* that we must understand, be it an economy's aggregate productivity, or the immune system's aggregate ability to distinguish antigen from self. (3) The interactions that generate this aggregate behavior are nonlinear, so that the aggregate behavior cannot be derived by simply summing up the behaviors of isolated agents.	Studying teacher education classes or college science classes (or the two together) is not sufficient to predict the formation of science teachers' actions and beliefs (Salish, 1997).
(4) The agents in CAS are not only numerous, but also diverse. An ecosystem can contain millions of species melded into a complex web of interactions; the mammalian brain consists of a panoply of neuron morphologies organized into a hierarchy of modules and interconnections; and so on.	At the heart of the system of science teacher preparation is the student. The system of science teacher preparation for biology teachers at Midwestern University also includes scientists who specialize in cell biology, biochemistry, genetics, physics and more. It also includes educators who specialize in multiculturalism, content area literacy, science education, computer technology, and again, more. Also part of the system are families, teachers in schools, both before coming to university and as part of the formal teacher education program. The list goes on.
(5) The diversity of CAS agents is not just a kaleidoscope of accidental patterns; remove one of the agent types and the system reorganizes itself with a cascade of changes, usually "filling the hole" in the process.	Different actors within the system fulfill different niches and niches change over time. The technology specialist who worked with movie and filmstrip projectors is a thing of the past.
(6) The diversity evolves, with new niches for interaction emerging, and new kinds of agents filling them. As a result the, the aggregate behavior, instead of settling down, exhibits a perpetual novelty, an aspect that bodes ill for standard mathematical approaches.	The current technology specialists work with computers, graphing calculators and all sorts of emerging technologies like Geographic Information Systems, global positioning systems and more.
(7) CAS agents employ *internal models* to direct their behavior, an almost diagnostic character. An internal model can be thought of, roughly, as a set of rules that enables an agent to anticipate the consequences of its actions.	The study participant Jason's internal model included the use of study groups and direct interaction with science faculty. Other seniors' internal models typically did not. Science professors McNair and Peters internal models included the use of standardized tests.

Table 2a: Complex Adaptive Systems and Science Teacher Preparation, adapted from (Holland, 1994)

In Complex Adaptive Systems…	Example from Science Teacher Preparation…
Delayed feedback complicates understanding and managing system dynamics.	The overwhelming nature of the first years of teaching may conceal impacts of teacher education programs – i.e. Salish showed more differences in teacher actions and stated philosophies within than between programs for beginning teachers. Even without this delay, the measure of what teachers do and believe typically does not flow in any direct way back to the teacher education programs from which they graduated (Salish, 1997).
Outcomes are sensitive to initial conditions	The most effective teacher education programs are those that take into account teacher candidates' initial conceptions of the teaching and learning process (Wideen, Mayer-Smith, & Moon, 1998) (LaBoskey, 1994)
The system evolves with occasional periods of rapid change.	There was a time when education courses at Midwestern were taught in large lecture halls and the program was completed in four years. Substantial reform of the teacher education program eliminated the lecture hall classes and moved the program from four to five years in duration.

Table 2b: Complex Adaptive Systems and Science Teacher Preparation

Industrial Agriculture and Industrial Schooling

The system of education and research within it has always been situated in the context of its time, informed consciously and unconsciously by the surrounding culture. The public school emerged as a factory model in an industrial time. I believe that in many ways, the system is more akin to industrial agriculture and factory farm than to the factory itself. See Figure 4.

In both industrial agriculture and "industrial schooling," crops are planted in rows, all receiving identical treatment. On a grand scale, in both settings, we attempt to create and impose a vast monoculture atop a diverse and multicultural system. This is highlighted by the implicit assumption that all students in a lecture hall are right-handed (again, see Figure 4).

Like the farmer providing roughly equal (and intending to provide exactly equal) amounts of water, fertilizer and pesticides to each seed in the plot, the professor comes and disseminates information equally to each student in the room. Each student receives (or is intended to receive) identical treatment. Those who do not blossom as a result of (or in spite of) the treatment are, of course, weeded out (although, Seymour and Hewitt (1997) found that success in science classes was not a predictor of whether or not students switched majors).

Like the farmer, outcomes for the scientists who teach are measured primarily quantitatively. Grade distributions, grade means and the number of students enrolled are the measures in science course work. Crop yield is key to the farmer. Grade yield is the key to the teaching scientist[2], although the scientist who teaches may or may not be seeking high yield. Industrial farming arguably causes losses of more qualitative measures like taste and health benefits. It also concentrates environmental impact in

[2] And perhaps graduate school yield – the number of students going onto graduate or professional schools from their undergraduate experience.

generally negative ways – think industrial hog farming. Scott uses scientific forestry as a parable for failed government intervention (Scott, 1998). This work together with David Orr's description of "architecture as crystallized pedagogy" (Orr, 1994, 1999) was the inspiration for Figure 4.

Figure 4a Rows of corn.

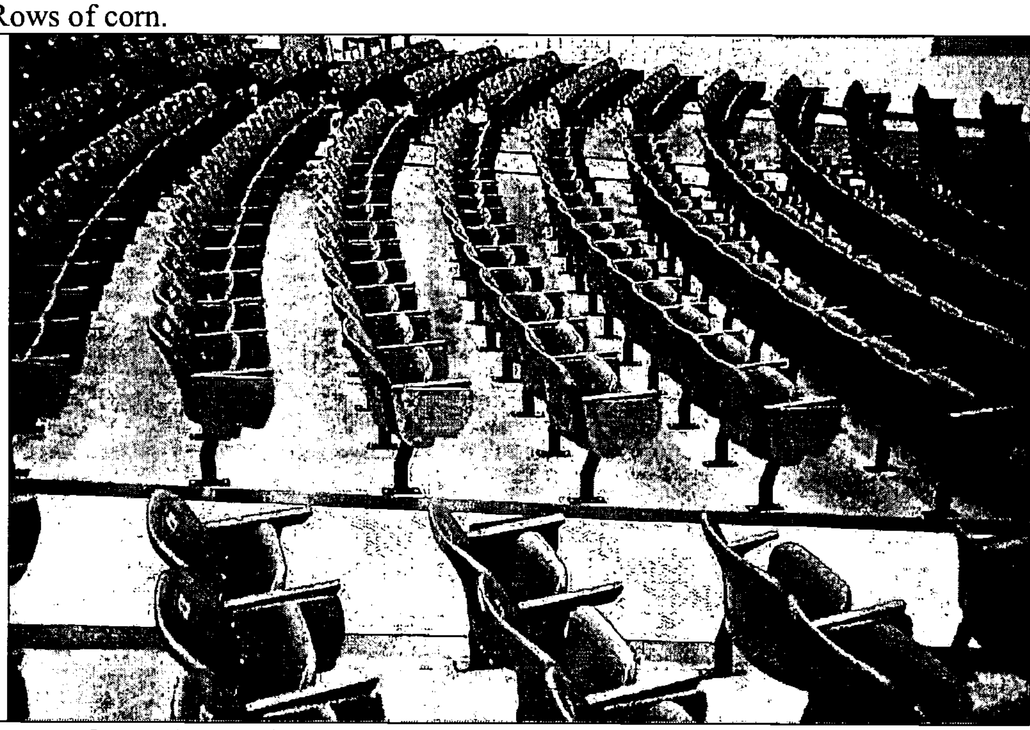

Figure 4b Rows of seats in a typical lecture hall.

Figure 4: Two examples of tightly controlled ecosystems that assume a monoculture.

Often systems that appear highly structured are rigid and ineffective. Conversely, systems that appear chaotic sometimes offer more effective control (Doll, 1989). In my observations of science and education classes the science classes had a more conspicuous structure and control appeared more effective in a quick glance. Conversely, in the education classes, students often were up and moving; conversations were taking place throughout the room and the professor's role was not always obvious. Looking deeper, I saw students sleeping each time I thought to look in the science classes but never in the education classes (unfortunately, I can not say the same of every education class I have ever taught!) The education students at least gave the impression of engagement. Science students often took copious notes, but also were far more likely to be absent and were more likely to do things like read newspapers in class.

Problems are compounded by delays in feedback

In both systems, delays in feedback make the system frustratingly difficult to understand. Delays can be a fairly small scale (i.e., the problem of feedback to students over the course of a semester by my own delays in grading) or much longer, like the lasting effect that a kindergarten teacher or a middle school reform might have on an adult in society. These feedback loops are the cycles that drive (or should drive) improvements in the system. A relevant pair of questions arises: What can be done to shorten feedback loops? How can we recognize and capitalize on feedback regardless of delays in feedback?

First cover

When an area is denuded (by fire, for example), the "first cover," the first species to take root will often dominate the landscape regardless of measures of efficiency of the species in the niche. Sometimes, in other words, it is not survival of the fittest, but rather survival of something that more or less fits but was there first. The lecture and lecture hall seems to fit into this category for the educational system. Its use is pervasive, embedded in the bricks and mortar of institutions and regarded by most who give it serious attention as deeply flawed. If you don't lecture, what would you do with the thousands of lecture halls in this country? Tenure is another example worthy of consideration.

Output is highly dependent on initial conditions

Sensitivity to initial conditions exists in both biological ecosystems and in human institutions. When teacher education pays attention to the initial understandings of the students enrolled in their programs, they are more likely to be successful (Wideen et al., 1998).[3] The National Research Council's summary of research on how people learn highlights this point:

[3] It is worth noting that while Wideen, Mayer-Smith and Moon both identify that starting with existing student understanding is a key component of successful programs and conclude by suggesting that ecological models should be explored thoughtfully for better understanding the learning-to-teach process,

> Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts and information presented in the classroom, or they may learn them for the purposes of a test but revert to their preconceptions outside the classroom. This finding requires that teachers be prepared to draw out their students' existing understandings and help to shape them into an understanding that reflects the concepts and knowledge in the particular discipline of study (Donovan, Bransford, & Pellegrino, 1999).

LaBoskey (1994) found "...that initial reflectivity tends to remain stable..." among the teachers in her study and that this was in agreement with the work of Butt and colleagues (1988). "[I]nterns seemed to follow the tendencies framed by their original patterns of thinking" (LaBoskey, 1994). In other words, the initial conditions had a powerful influence over program outcomes.

This may help to explain the high and growing esteem of Midwestern's program. The esteem of the program allows for selectivity – only about half of applicants are accepted (students typically apply in their junior year). This creates a feedback loop – a quality program attracts quality applicants which builds a quality program.
Midwestern University's Teacher Education coursework seems to consider initial conditions, students' conceptions of teaching and learning, fairly well. The science courses observed, conversely, treat the students as a vast monoculture. See Figure 4.

Niches
We can see that each actor in a system occupies a niche and we can perhaps grasp some of the complexity of what that actually means. I have found that even graduate students in biological sciences hold naïve conceptions of what a niche is. It is not simply the job of an organism in the environment, or at least more sophisticated definitions have emerged for use in ecological research.

The idea of a Hutchisonian niche indicates the complexity of niches. Hutchison defined a niche as a "multidimensional hypervolume" with niche axes (Hutchinson, 1957). The niche can be described as the range of biotic and abiotic variables in which a species can survive and grow. Each of those variables is described on its own niche axis, and thus the multidimensional hypervolume. Axes might include temperature, soil composition, and humidity. A species niche defines not only its role, consequence, function or impact, but also its constraints. Food is likely to be a limiting factor in a niche, oxygen as it is present in most ecosystems, is not likely to be limiting.

What might be the niche axes for teachers? Some suggestions: content knowledge, ability to work with colleagues, classroom presence, understanding of how new

they do not draw the comparison to the importance of initial conditions to the outcomes of ecological processes. Their work also focuses on understanding future teachers' understanding of the teaching and learning processes and does not include what happens outside of colleges or departments of education.

knowledge is created in the subject matter, pedagogical perspective, availability and use of curriculum materials. How would you measure these things? How would the niche axes of university faculty be described?

Emergent Properties

> "Water is H_2O, hydrogen two parts, oxygen one. But there is also a third thing that makes it water and nobody knows what that is."
>
> D. H. Lawrence

A product with "characteristics beyond those of its combined elements" is said to have emergent properties (Campbell, 1996)[4]. Repeatedly throughout the dissertation I used the useful simplification that treats college science and teacher education as two monolithic bodies alternately working with future science teachers. Future science teachers at Midwestern and across the country are left to their own devices to integrate the two program components into a coherent whole (Wideen et al., 1998)[5]. How these disparate pieces are typically summed together has contributed to a K-12 educational system that is nearly universally recognized as deeply troubled.

In any complex system, properties emerge which cannot be predicted solely from the study of less complex levels within the system. While it is useful to study college science teaching and teacher education in and of themselves, this kind of study can never reveal the actual workings of the total system. The emergent properties of the combination of the parallel systems of college science education and teacher education do not fulfill the goals of either program component, of either science or education.

FIGURE 2.2
The emergent properties of a compound. The metal sodium combines with the poisonous gas chlorine to form the edible compound sodium chloride, or table salt.

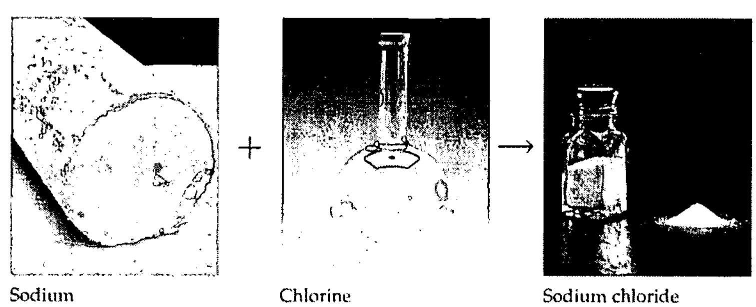

Figure 5: The illustration for emergent properties used in the BS111 text (Campbell, 1996) p. 26.

[4] This definition and Figure 2 are taken from the text for BS111; an introductory biology course observed in the dissertation study.

[5] Again, there are hints of making these connections with the teacher candidates in TE401; a senior level teacher education course observed in the dissertation study, but the teacher candidates themselves do not report this connection.

Complexity is messy

The classroom shown in Figure 4 appears neat and orderly. The teacher education classes I observed (and the ones I teach) cannot be described as neat and orderly. This messiness often breeds frustration, but the imposed order of the lecture hall doesn't eliminate disorder. It may reduce it superficially, but, again, students in the study were more likely to be sleeping or reading the paper in the orderly science classes than in the superficially disorderly education classes. Students in the education classes were far more likely to actually discuss the content of the class during the class time than they were in the science classes (though in the science classes, they were more likely to discuss the content in semi-formal study groups outside of class time).

The Species-Area Relationship

The amount of territory a species needs in order to avoid extinction is known as the species-area relationship[6]. How much space does a kind of teaching need to survive? How many teachers in a school, for example, are required for a non-traditional approach to instruction need to survive (or thrive)?

If a frog in a swamp sets out to change his niche as the other frogs continue along in their old ways, the likelihood of change seems remote. One frog singing a different tune will be drowned out by the chorus. If two frogs sing a new tune, it seems a tad more likely that they can sustain each other, but again, the likelihood of lasting change seems remote. How many frogs does it take to change the tune? Obviously, that depends on a number of factors. How many frogs are there in total? How big is the swamp? Is the new tune better in some way understandable to the other frogs?

Conclusions

There are indications that we can predict more about how a teacher will develop as a professional from her initial conditions upon entering a teacher education program (LaBoskey, 1994) and from understanding the nature of the school that she enters into than from the teacher education program she completes. This shouldn't seem surprising yet it doesn't seem to relate much to what reforms in teacher education programs often look like. NEED TO ADD CITATIONS HERE. Midwestern University's Teacher Education coursework seems to consider initial conditions, students' conceptions of teaching and learning, fairly well. The science courses observed, conversely, treat the students as a vast monoculture. Again, see Figure 4.

[6] First proposed by Arrhenius 1918] Arrhenius, O. 1918. En studie ¨over yta och arter (A study of area and species). Svensk. Bot. Tidskr. 12; In English; Arrhenius 1921] Arrhenius, O. 1921. Species and area. Journal of Ecology 9:95- 99

Three important matters in teacher development are context, context and context. The context that teacher candidates come from (the initial condition from the source)[7]; the context of the teacher education program itself (including the content area courses and school based fieldwork); and the context where the teacher finds employment (which I suspect is ultimately the most important factor). The settings where the teacher has the longest immersion in the context (before and after the teacher education program) understandably have the greatest influence on how a teacher teaches. This should be seen as a signal that teacher education programs should not come to close with the awarding of the teaching certificate. Connections between teacher education programs and professional programs in schools should be made more integrative – the seam between preservice and inservice teacher education should become less obvious.

Both the systems of science teacher education and industrial agriculture are human designed to manage natural processes – learning in the former and the growth of plants and animals in the latter. Both systems attempt to simplify complex processes that are hierarchical, non-linear and self-organizing. Both systems have been managed through Holling's first type of science though they fit more clearly into the second integrative science. And both are simultaneously remarkably successful and deeply troubled.

As Fullan noted, "Change is technologically simple and socially complex" (Fullan, 1991). Fully understanding the depth of this complexity is beyond our capabilities, and even if we did fully grasp it, there are aspects that would remain beyond our ability to predict. The two streams of science that Hollings speaks of are hardly new to debates of educational research; in some ways this maps onto the false debate between qualitative and quantitative research. Ecologist Pahl-Wostl draws the dichotomy as mechanistic and relational sciences. See Table 3.

This relational science doesn't lead to what is sometimes referred to as the gold standard of scientific research: large scale randomized trials of some new technique. For some, (especially in the current federal government) that might be taken to mean it is not scientific. Such a view represents a narrow view of science that also would preclude Darwin's work and research in subatomic physics.

	Mechanistic	Relational
Question:	What are the causes for an even [sic] to happen?	What are the characteristics rendering possible a pattern of interactions?
Goal:	Derive causal mechanistic explanations for system dynamics	Find relationships between structural and functional properties
Method:	Identify and isolate entities and processes	Identify patterns of interaction and their requirements
Theory:	Models that predict events	Models that make patterns intelligible
	Rules how processes act on entities to produce events	Rules on how to proceed in detecting and characterizing relational patterns

Table 3. Comparison between a mechanistic and a relational approach. (Pahl-Wostl, 1995)

[7] I do not wish to give the impression that human nature doesn't matter; that in a nature vs. nurture debate only nurture matters. That is not amongst my claims – nature is part of the initial condition.

> "…educational research often focuses on curriculum, teaching or learning, but does not consider them as a dynamic relationship that is mutually influential" (Hoban, 2000 in Hoban 2002, p. 28).

Not only should the seams between preservice and inservice education become less obvious, but the seams internal to both systems should also become less obvious – a curriculum class that is poorly connected to a methods class, for example is problematic.

How can the use of these models inform our research and our program development? Whole systems design, the idea that effective systems are most likely designed when considered from a multitude of viewpoints and when stakeholders collaborate in the design process hardly seems like a revolutionary idea, but it is rare in most complex systems from building design to educational design. This leads to ways we might meld the seams into the system.

How can we work more effectively in an environment where we can never realistically hope that our models will never be more than weakly predictive? For one thing we need to help others understand that with the laws of nature, that's the best we can ever do in a system as complex as the educational system.

This understanding does allow one to release blame – there is an abundance of bad teaching at virtually every level of American education (possible exceptions might be kindergarten and advanced graduate school, where instruction is really built around the learner). No one and no one group of individuals made this system. It evolved over time shaping the actors in the system as the actors shaped the system:

> "Organisms within their individual lifetimes and in the course of their evolution as a species do not adapt to environments; they construct them. They are not simply objects of the laws of nature, altering themselves to bend to the inevitable, but active subjects transforming nature according to its laws." (Lewontin, 1982, p. 163)

While all of us have responsibilities to improve the system, its greatest faults emerged through an evolutionary process over a long, long time.

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